Surface Water and Ocean Topography Mission –

SWOT 101

A quantum improvement for oceanography and hydrology from the next generation altimeter mission

Contributions by JPL, SSC, CNES, the SWOT Project, and the SWOT Applications teams

More info: swot.jpl.nasa.gov
http://www.aviso.altimetry.fr/swot

Outline

- SWOT mission description
- Oceanography
- Hydrology
- Synergistic science
- Data products
- Summary

SWOT Mission Overview

- The Surface Water and Ocean Topography mission (SWOT) is a satellite mission recommended by the US National Research Council 2007 Decadal Survey (DS) that will provide a quantum improvement for oceanography and hydrology

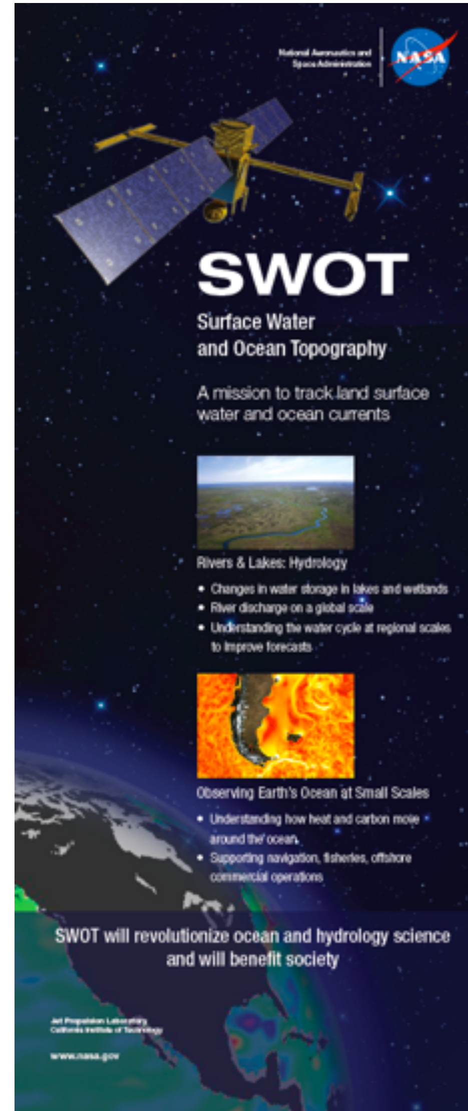
- Oceanography: First global determination of the ocean circulation, kinetic energy and dissipation at high resolution

- Hydrology: First global inventory of fresh water storage and its change on a global basis

- Planned launch: October 2020

Major Partnership: NASA and CNES

- Planned as a major partnership between NASA and the French Space Agency (CNES).
- Continues a 20+ year partnership NASA and CNES of the highly successful altimetric oceanographic satellite missions
- Additional contributions from the Canadian Space Agency (CSA) and the United Kingdom Space Agency (UKSA)



Mission Science

Science questions to be addressed by this mission concept

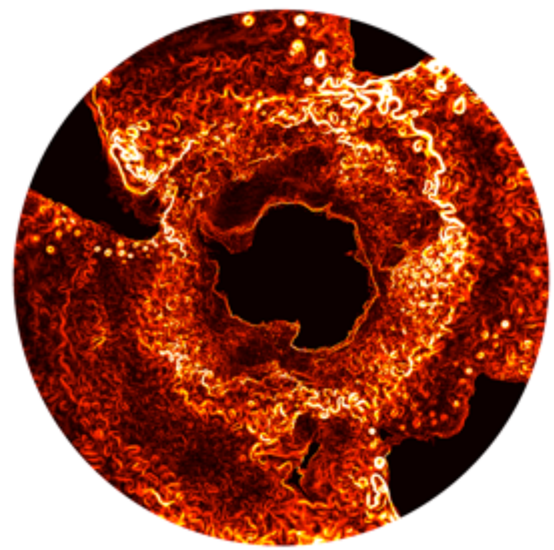
Hydrology

What is the spatial and temporal variability in the world's terrestrial surface water storage and how can we predict these variations more accurately and on a global scale? Can we measure river discharge and flux?

Image. L. Smith

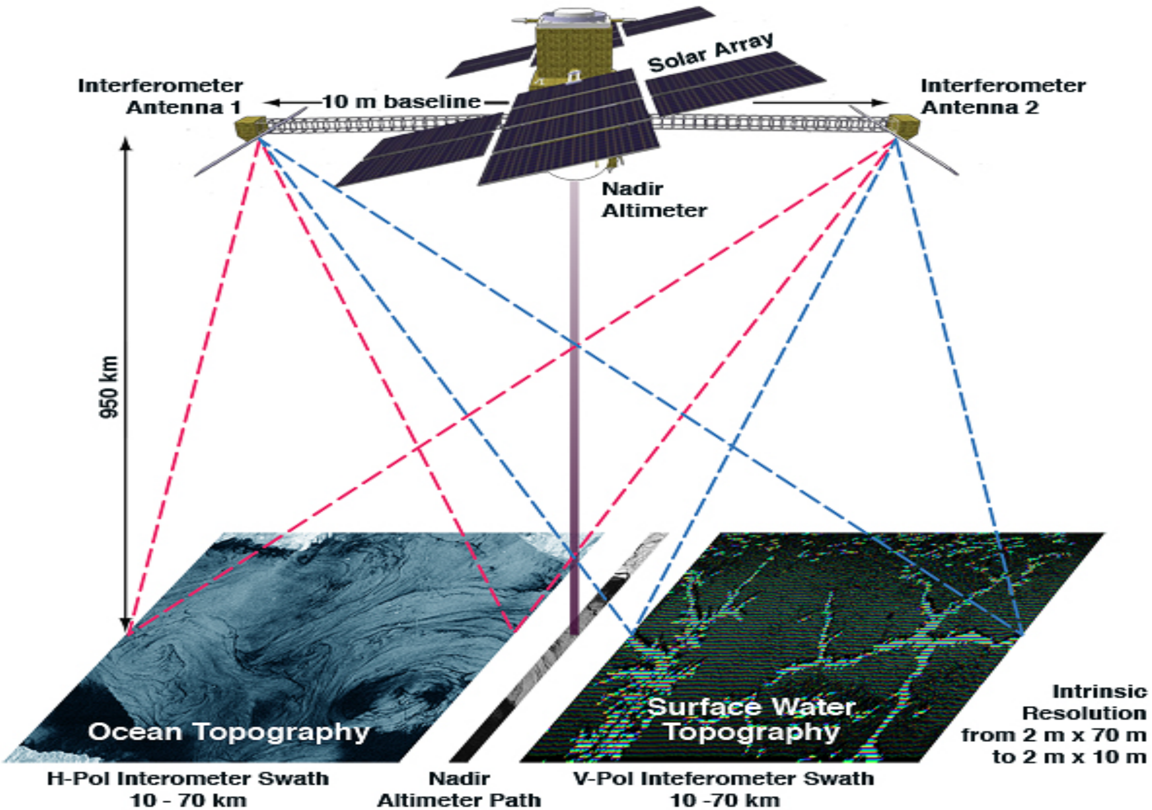
Oceanography

How well can we resolve the ocean at spatial scales of less than 100 km? What is the variability of ocean surface topography that determines the velocity of ocean currents, especially in the coastal zones? What are the effects of coastal currents on offshore operation, navigation, and ecosystem?



Southern Ocean near-surface current speed from ECCO2

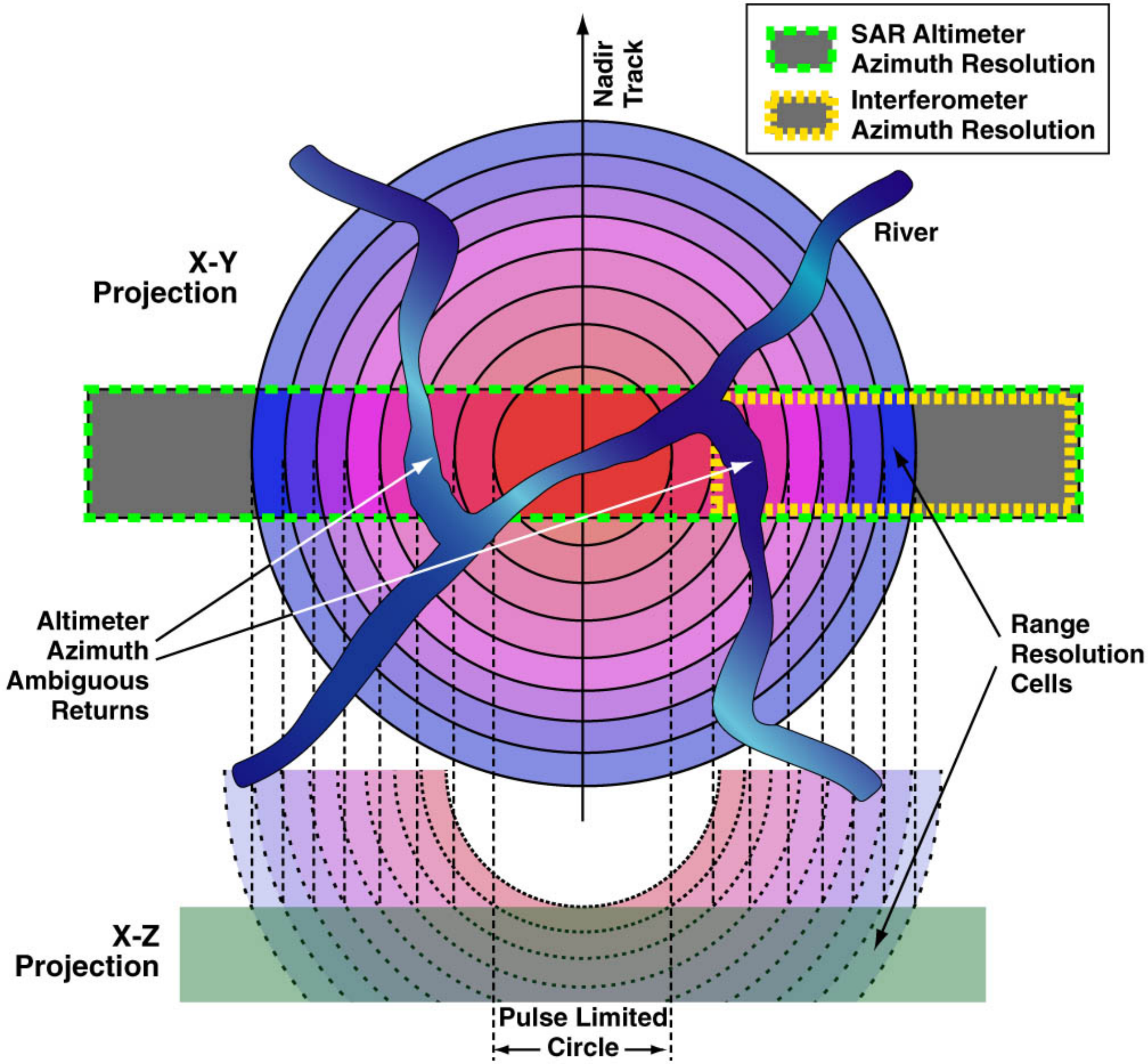
SWOT Measurement Concept



- Ka-band SAR interferometric (KaRIn) system with 2 swaths, 50 km each (10 – 60 km from nadir, ~1-4 deg)
- Produces heights and co-registered all-weather imagery
- Use conventional Jason-class altimeter for nadir coverage, radiometer for wet-tropospheric delay, and DORIS/GPSP/LRA for Precision Orbit Determination.

- **Major partnership of NASA-CNES, with additional support from CSA and UKSA**
- Science mission duration of 3 years
- Cal orbit: 857 km, 77.6º Incl., 1 day repeat
- Science orbit: 891 km, 77.6º Incl., 21 day repeat
- Flight System: ~2000kg, ~1900W
- Launch Vehicle: NASA Medium class
- Planned Launch Readiness: Oct 2020
- Entered Phase B June 2014

Radar Spatial Resolution



- Conventional real-aperture altimeter spatial resolution is determined by iso-range annuli and antenna beamwidth
  - Left/right/front/back ambiguity
  - Pulse limited circle gives geolocation
- Synthetic aperture processing narrows the along-track (azimuth) cell size
  - Left/right ambiguity is not resolved
  - Clutter from land is reduced
- Interferometer resolves left/right ambiguity by illuminating only one side of the swath

E. Rodriguez, 2010

KaRIN Measurement Characteristics

- Ka-band SAR interferometer (KaRIn) 10 m baseline with 2 swaths, 50 km each (10 – 60 km from nadir, ~1-4 deg incidence)
    - Because of near-nadir geometry, ground range resolution varies from about 70 m near swath to 10 m far swath
- Downlink Data
    - Ocean Low Rate (LR, ~2.4 Mbps) data would be produced by Onboard Processor (OBP) all the time. Main use for ocean, large lakes. Planned resolution: 1 x 1 km with error at 1.5 cm/km^2 (Note that height error scales as pixel area.)
    - Land High Rate (HR, ~350 Mbps) data when turned on by mask (nadir point). Presum by ~2 to reduce data rate. Main use for surface water.
        - Coverage limited by available downlink data rate (620 Mbps), transmit and station time, ground links.
        - Full SAR processing on ground
    - Total daily downlink data volume (7.15 Tb/day).
- ~21 day orbit repeat would give nearly full swath coverage at equator

KaRIN High-resolution mode Land mask

- Ocean Low rate data – available globally over all surfaces
- High-resolution data - turned on when nadir measurement is 3km from land
- Nominal HR coverage would be 22.4% of orbit cycle (Includes 3 km buffer around land. Partial coverage of Australia, islands, Greenland; no Antarctica.)
  - Data acquisition mask is uploadable. Plan to reload seasonally
  - Global 5 km extension of mask adds ~1% of total data

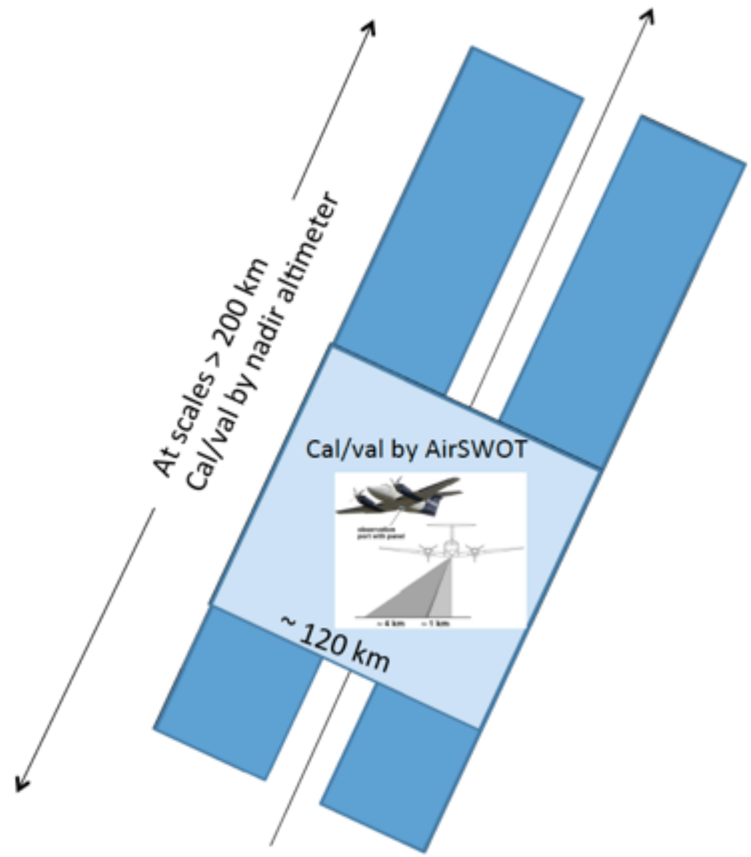
Need of the Nadir altimeter

- The long-wavelength accuracy of the SSH measurement is expected higher for the altimeter than KaRIn.

- By combining the two measurements simultaneously, a consistent measurement from short (KaRIn) to long wavelengths (altimeter) can be obtained.

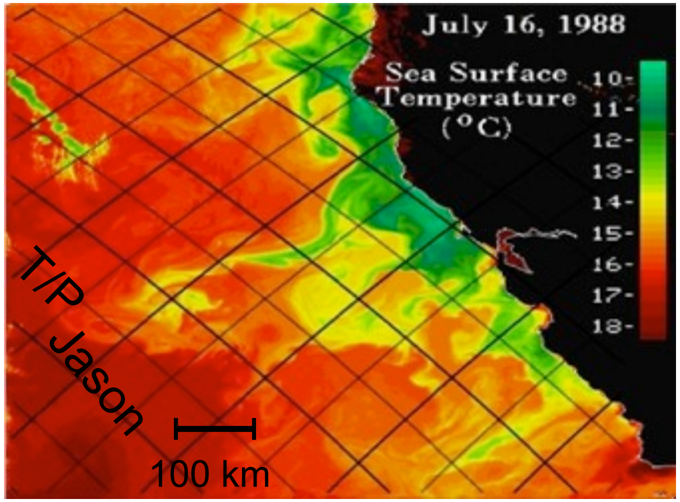
- Strong heritage of error analysis from nadir altimetry (T/P, J1, J2, Saral/AltiKa, …)

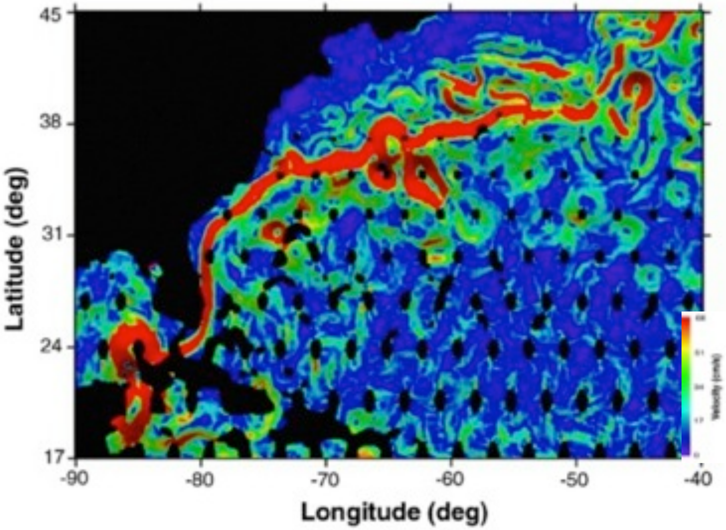
- Calibration and validation of SWOT in setting the standard for the next generation altimetry missions to continue the climate data record of sea level and improve its resolution and coverage.



Oceanographic Objectives

- **Ocean topography** is an analog of atmospheric surface pressure: ocean currents flow around the highs and lows of ocean topography, like winds blow around the highs and lows of surface pressure.
- **Satellite altimetry** over the past 25 years has made measurement of **sea level change at scales larger than 200 km**: ocean gyres, El Nino, sea level rise, large eddies.
- **Ocean currents and eddies at scales shorter than 200 km, containing most of the kinetic energy of the ocean,** play key roles in the transport of heat, carbon and nutrients. They affect climate via modulation of sea surface temperature and heat flux, as well as the oceanic uptake of carbon from the atmosphere.

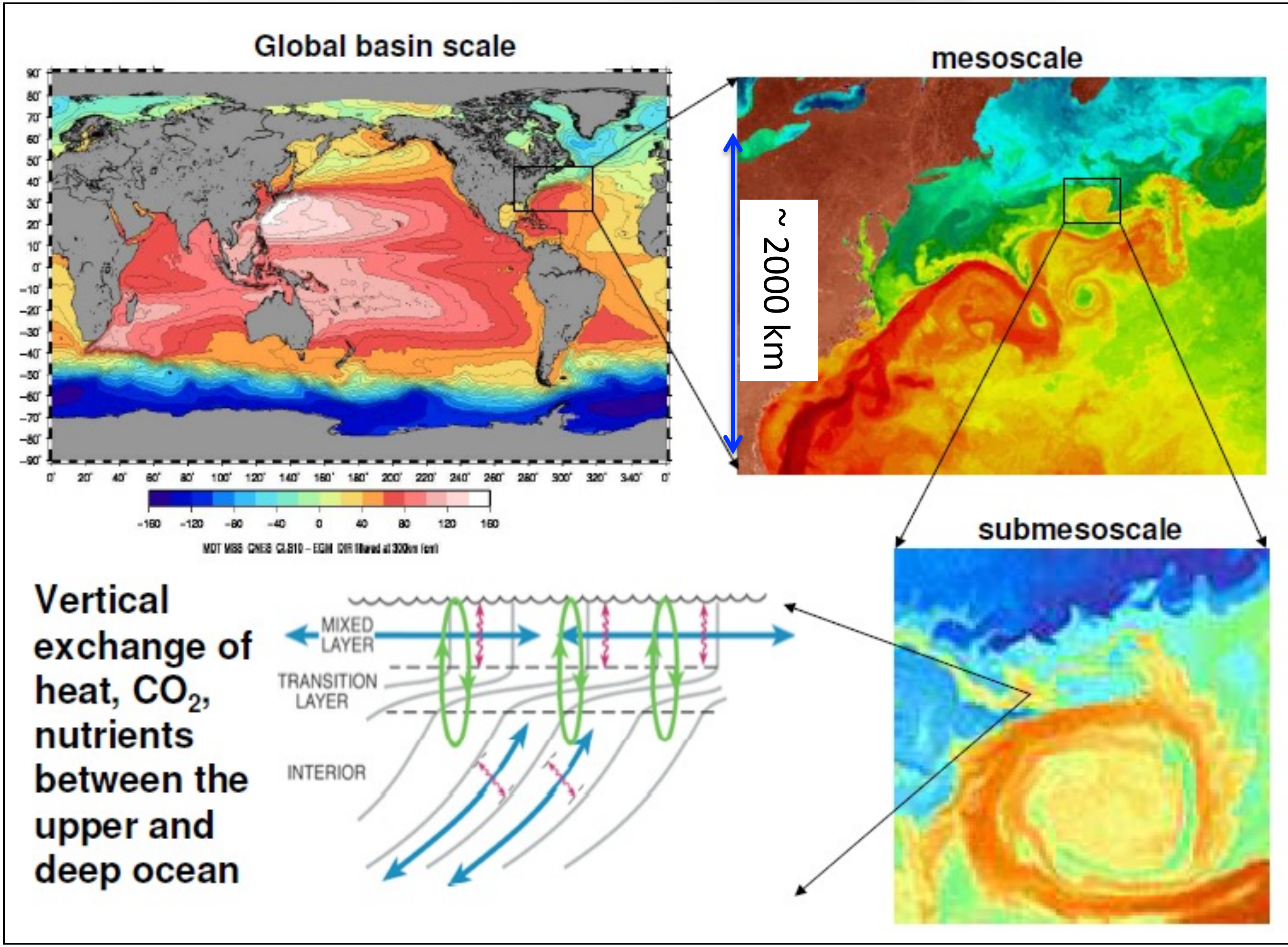




Oceanographic Objectives (cont)

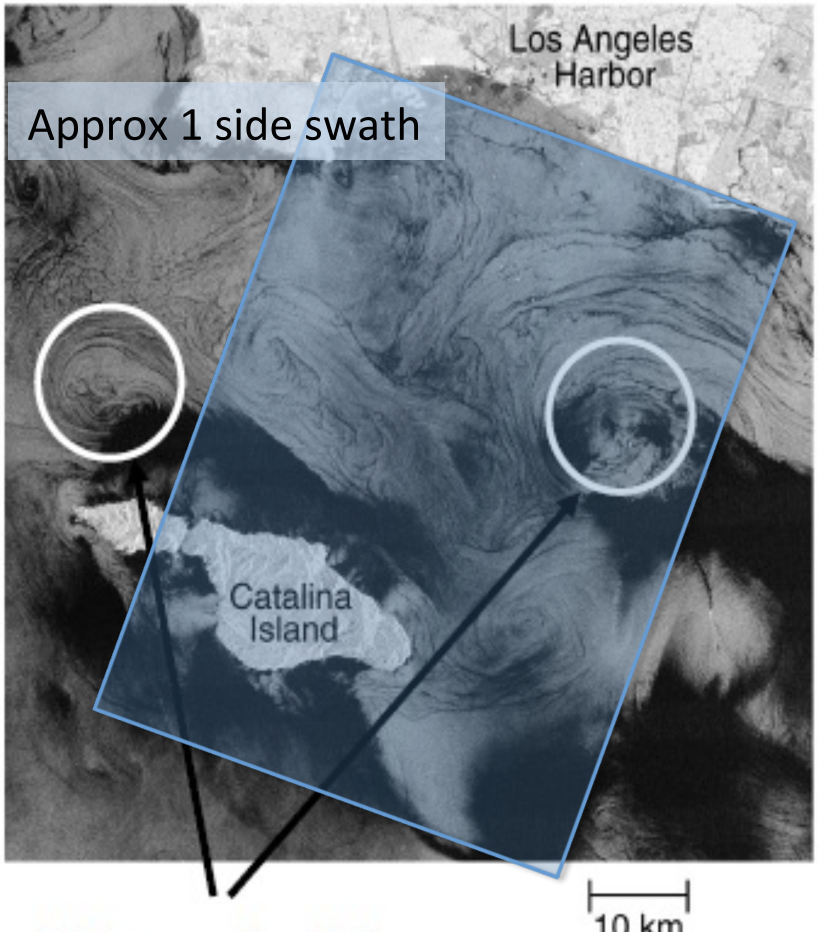
- Ocean currents and eddies at these short scales are also important to **coastal ocean processes of importance to societal applications.**
- **The primary oceanographic objectives** of the SWOT mission are to observe the ocean mesoscale and submesoscale circulation at spatial resolutions of 15 km and larger, **providing the missing link between 15 and 200 km for ocean climate studies**.

Targeting the Smallest Scales of Ocean Circulation



Submesoscale Ocean Processes

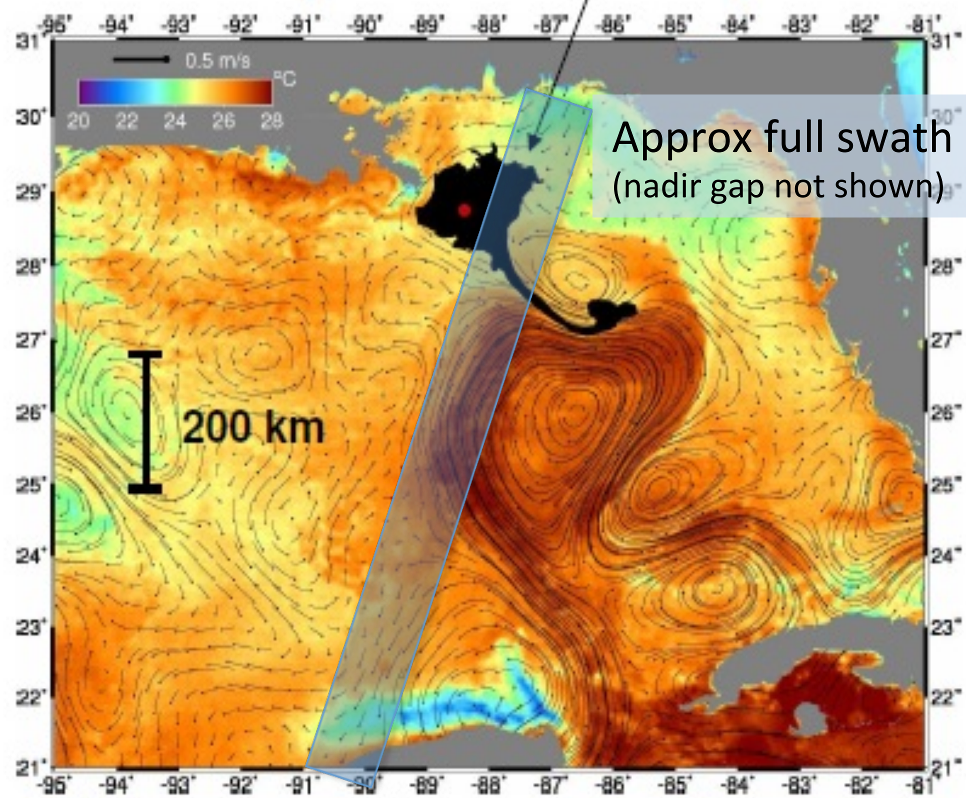
RADARSAT - December 26, 1998



10 km scale eddies Resolvable by SWOT*

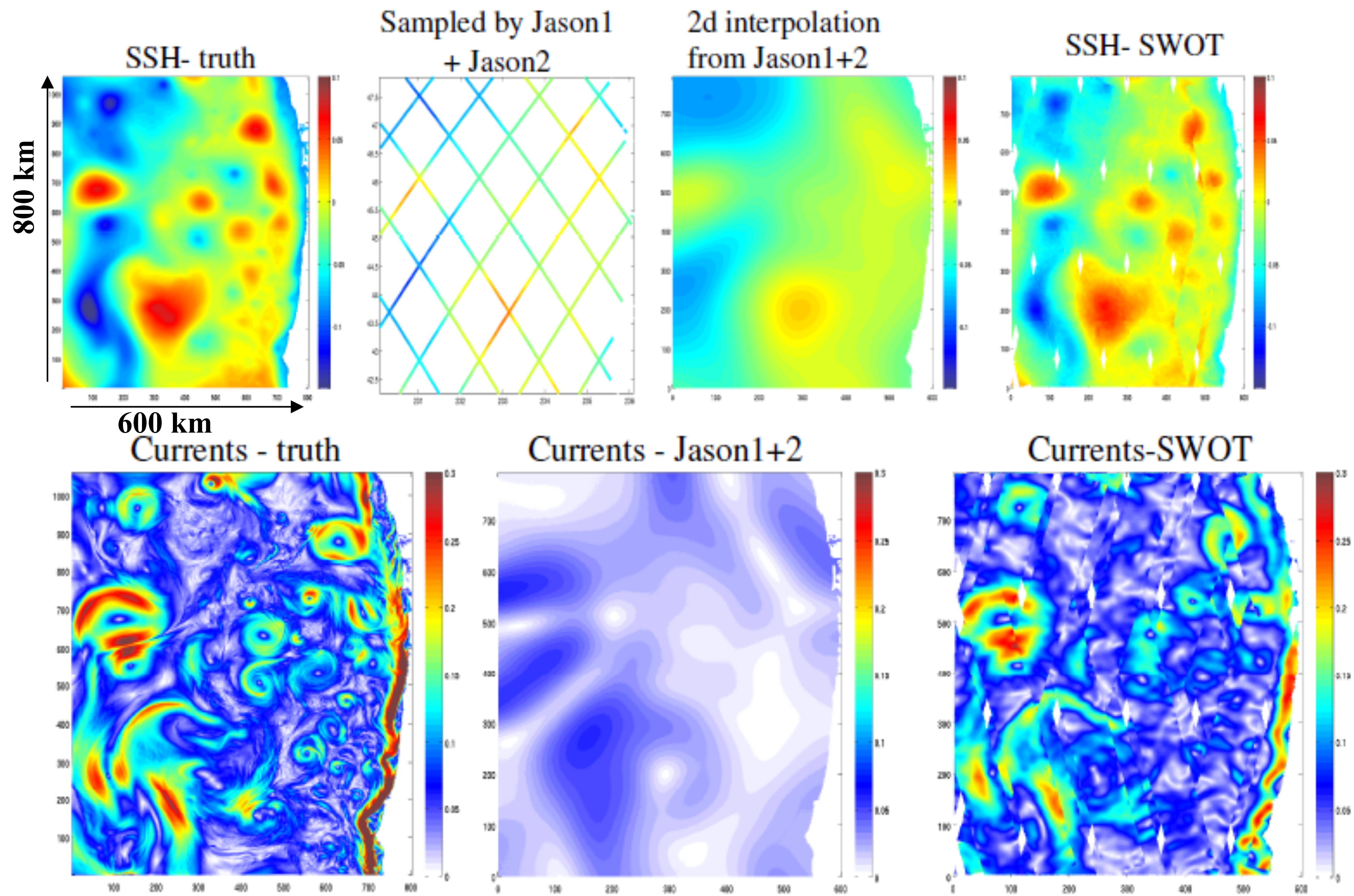
*Proposed Mission – Pre-decisional – for planning & discussion purposes only

Deepwater Horizon oil spill



The missing information at the submesoscale is important for predicting the dispersal of pollutants in the ocean.

Simulated SWOT Ocean Observations – US West Coast

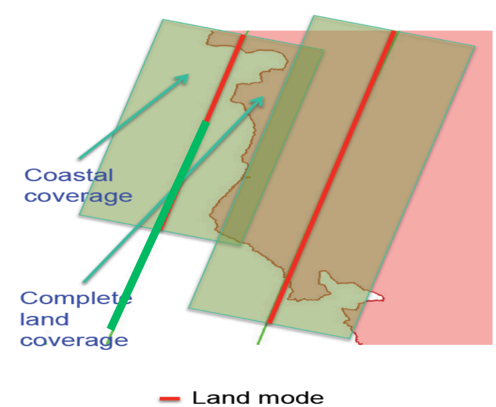


SWOT Ocean Data Products

- Ocean data (Low Resolution, LR) would be produced by an Onboard Processor (OBP). 2 swaths 10 – 60 km from nadir.
  - Requires ~1 m range accuracy based on onboard tables and ephemeris from DORIS, so mixed ocean/land, large coastal tide pixels may have problems
  - Planned resolution: 1 x 1 km with error at 1.5 cm/km^2. (Requirement is 2 km. Note that height error scales as pixel area.)
- Planned Ocean data product would be passes of Earth-fixed, swath-aligned 1 km grid with sea surface height, slope, sigma0, error information, geophysical corrections (tropo, etc.) and fields (tides, MSS, etc.).
- Goal to provide wind speed, SWH.

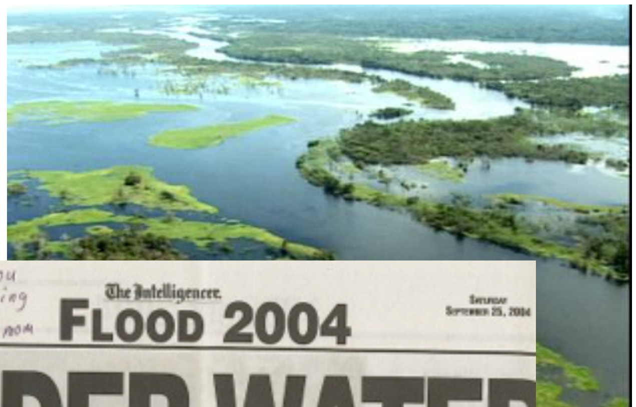
SWOT* High Resolution Data for Coastal Altimetry

- High Rate (HR) data would be turned on when nadir measurement is 3km from land – coastal ocean coverage depends on orbit/land/water configuration
- Planned HR data product would be ~140 km tiles with pixel cloud of points that can be geolocated adequately (~0.1 pixel size) with height, sigma0, area, orientation, geophysical corrections and fields
  - Extract vector products from pixel cloud
- HR data over coastal ocean could be processed to resolution >~ 70 m for super-fine resolution, but with increased noise ~area (noise at 1 km slightly higher than LR because of presum).
- A localized coastal product containing both LR and HR data could be defined



What hydrology issues will SWOT address?

1. The Problem **In-situ cannot measure this.**




Hi! Thought you might enjoy seeing this! Mom

The Intelligencer — Saturday September 25, 2004

FLOOD 2004

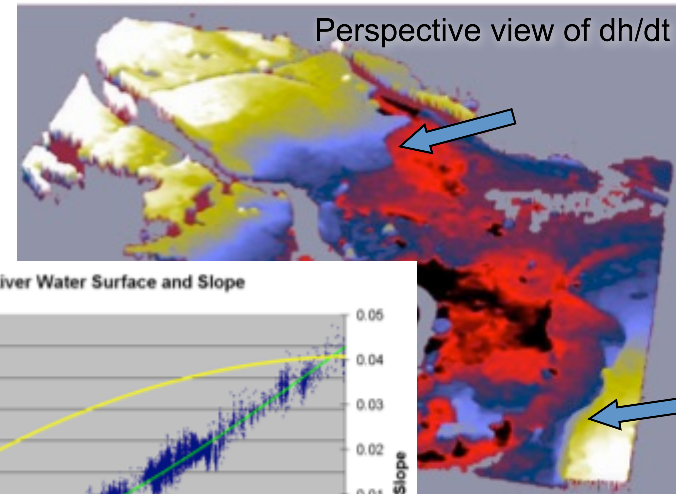
UNDER WATER

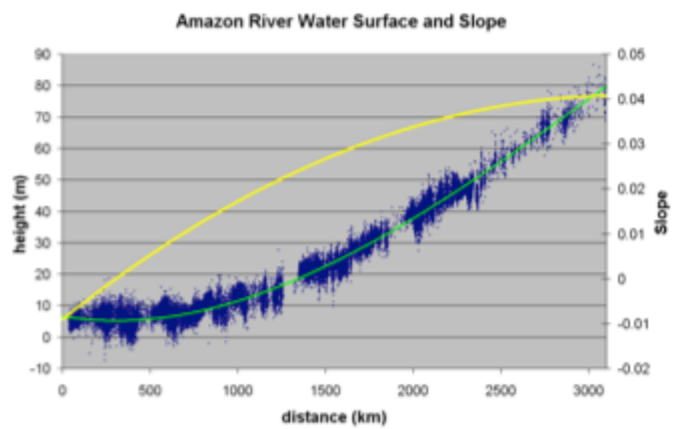
The rains seemed as if they would never stop Friday afternoon, Sept. 17. And then, all hell broke loose. Roads turned into rivers, streets into streams, hillsides into mudslides. And creeks invaded neighborhoods. Then the Ohio River joined in.

Floods are a significant hazard

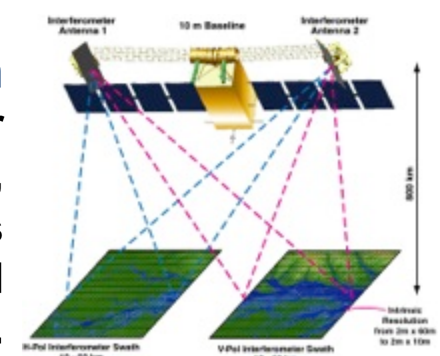
2. The Question **What is the spatial and temporal variability of freshwater stored in the world's terrestrial water bodies?**

3. Measurements Required **Maps of h, which give maps of dh/dt and dh/dx**



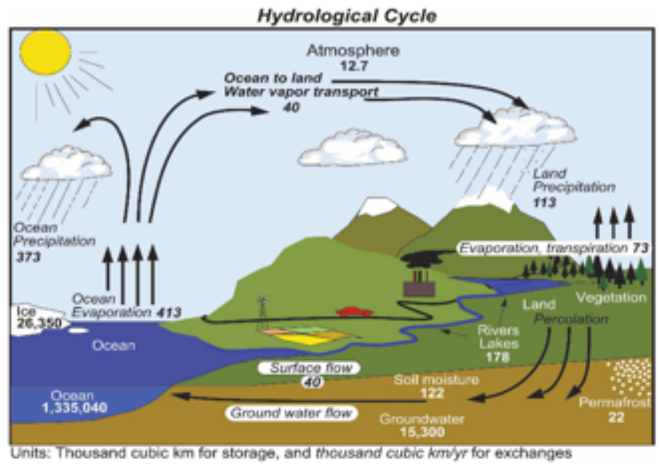


4. The Solution **KaRIN: Ka-band Radar Interferometer. SRTM, WSOA heritage. Maps of h globally and ~weekly.**



Hydrologic Objectives

- Surface water in rivers, lakes, and wetlands uniquely integrates spatially distributed signals from all components of the terrestrial water cycle. As such, measuring surface water storage and fluxes reveals spatial and temporal patterns in the water cycle.



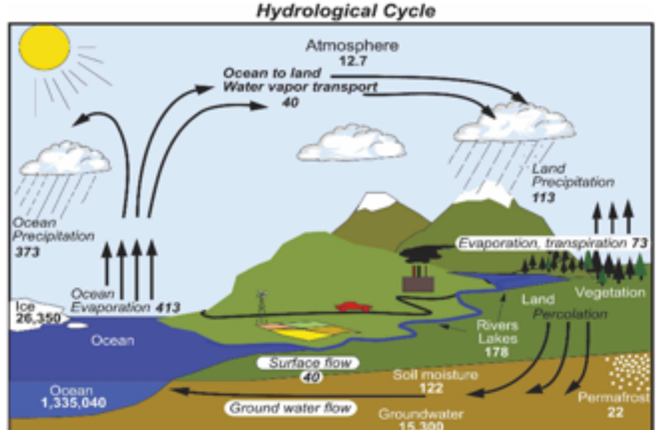
Trenberth et al., 2007

- Current global observation capabilities of surface water are insufficient to characterize the present-day water cycle:
  - The flux of water through rivers is known to approximately +/-20% at large scales but not at scales small enough to reflect the dominant processes governing the water cycle.
  - Water storage can only be measured in the largest lakes and reservoirs, but most variability in water storage is in smaller water bodies.
  - There are no consistent global measurements of water storage in wetlands

Hydrologic Objectives (cont)

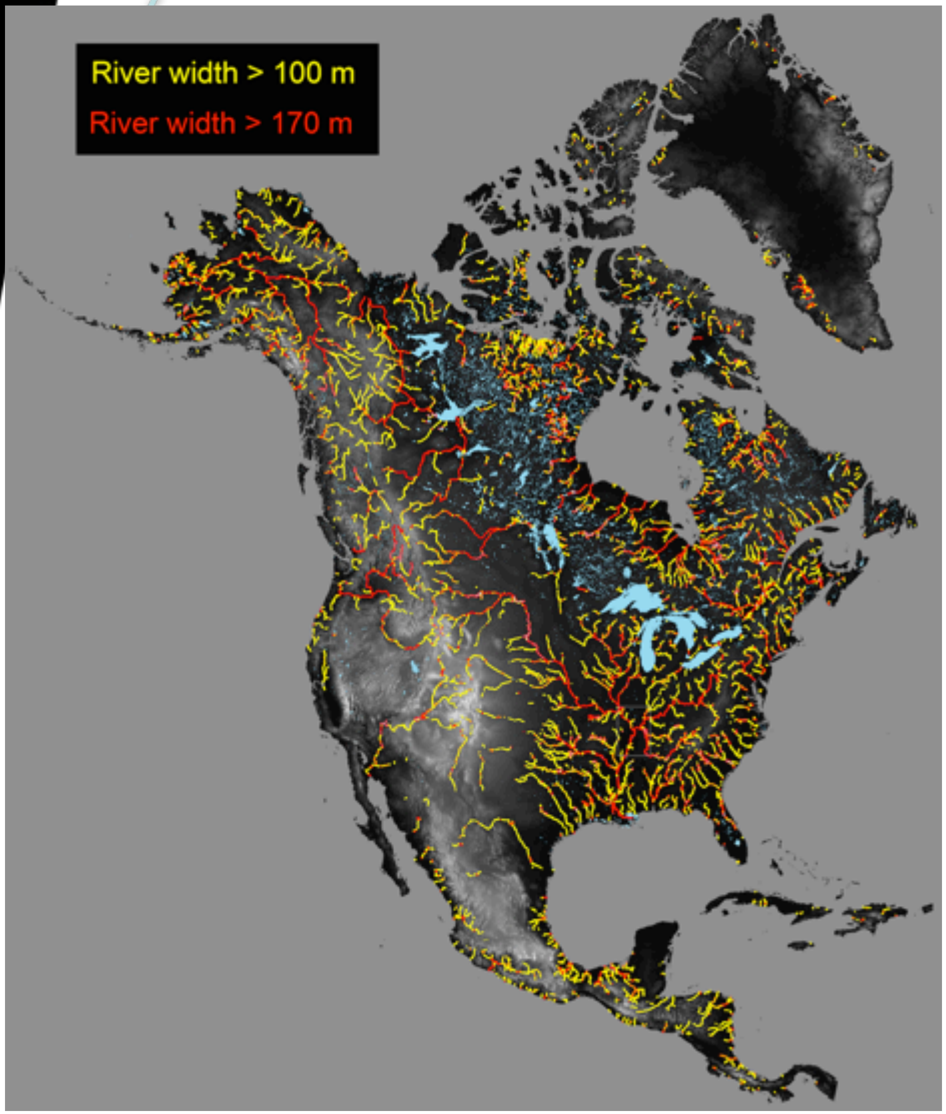
- The hydrologic science measurement objectives for SWOT are:
  - To provide a **global inventory of all terrestrial surface water bodies** whose surface area exceeds **(250m)^2 (lakes, reservoirs, wetlands)** and **>10km long river reaches whose width exceeds 100m (requirement)**.
  - To measure the global patterns of change in storage in terrestrial surface water bodies and river discharge at **sub-monthly, seasonal, and annual time scales**.

Hydrological Cycle



Units: Thousand cubic km for storage, and *thousand cubic km/yr* for exchanges

SWOT Performance Requirements: Rivers



From Allen et al., in press, GRL

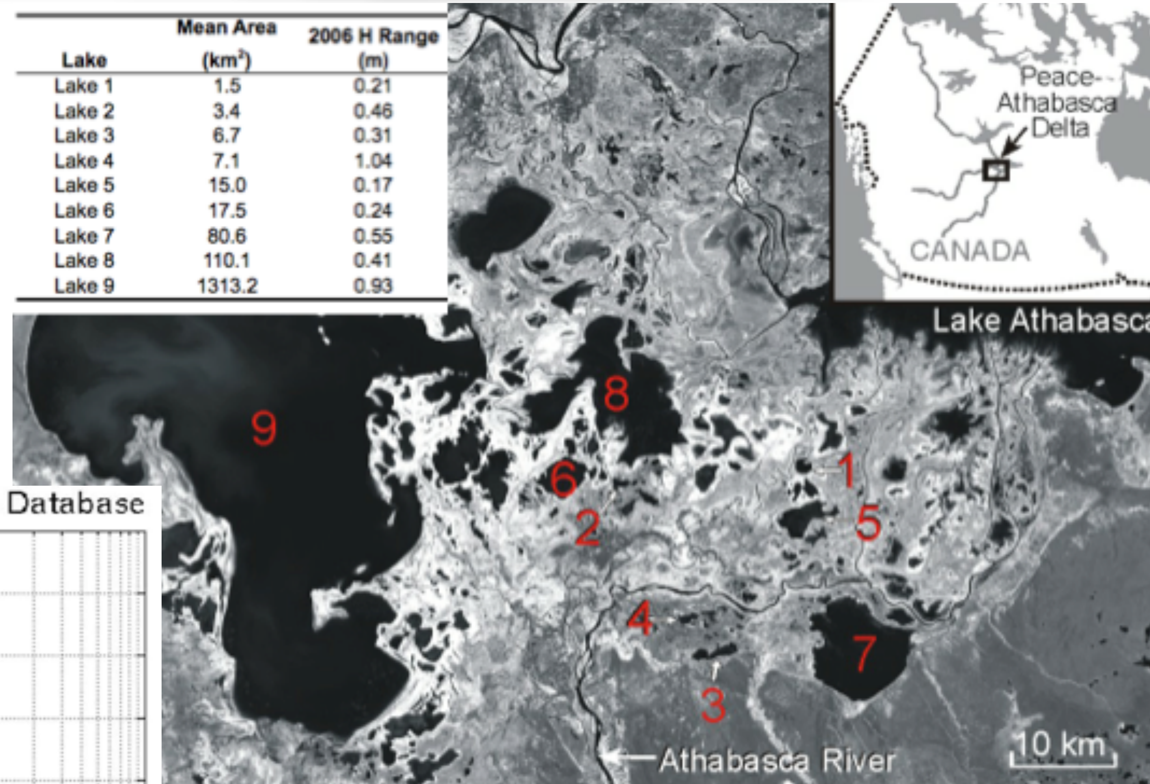
- Inundated Area/River Width:
  - 15% error for 100 m wide rivers over 10 km reach (baseline)
  - 15% error for 170 m wide rivers over 10 km reach (threshold)
- Water surface elevation/height:
  - 10 cm error for 1 km^2 area and 25 cm error for between (250 m)^2 and 1 km^2 (baseline)
  - 11 cm error for 1 km^2 area (threshold)
- Water surface slope:
  - 10 μrad error for 100 m wide river over 10 km (baseline)*
  - 20 μrad error for 100 m wide river over 10 km (threshold)*

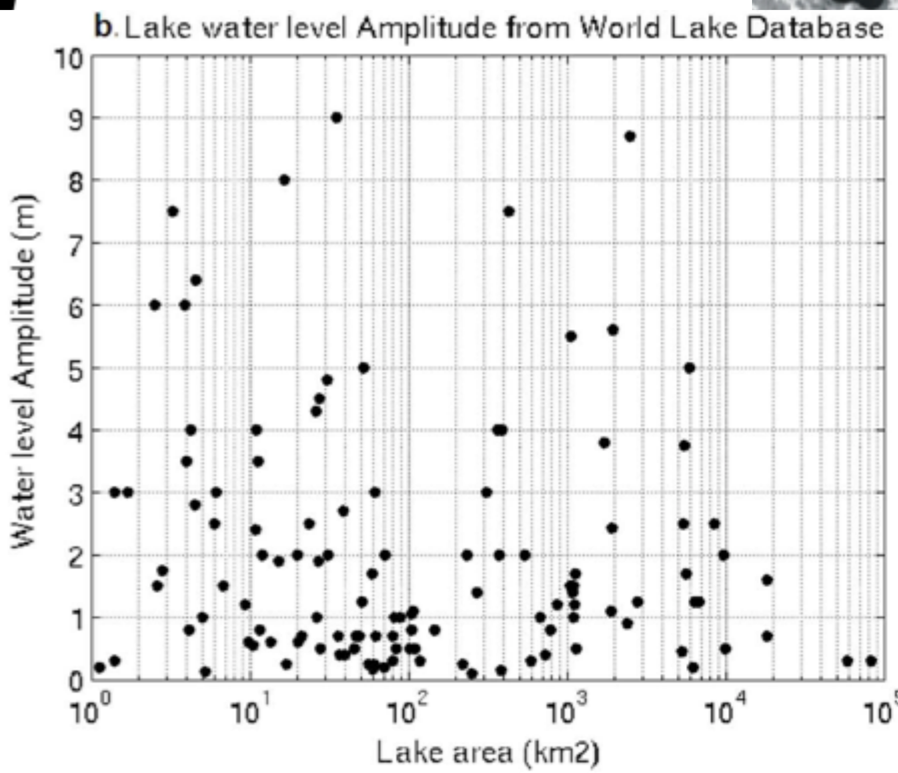
*Nominal

SWOT Performance Requirements: Lakes

- Inundated Area:
  - 15% accuracy for lakes larger than (250 m)^2 (baseline)
  - 15% accuracy for lakes larger than 1 km^2 (threshold)

Lake	Mean Area (km^2)	2006 H Range (m)
Lake 1	1.5	0.21
Lake 2	3.4	0.46
Lake 3	6.7	0.31
Lake 4	7.1	1.04
Lake 5	15.0	0.17
Lake 6	17.5	0.24
Lake 7	80.6	0.55
Lake 8	110.1	0.41
Lake 9	1313.2	0.93





- Lake Water Surface Height:
  - 10 cm accuracy for lakes larger than 1 km^2 and 25 cm accuracy for lakes between 1 km^2 and (250m)^2 (baseline)
  - 11 cm accuracy for lakes larger than 1 km^2 (threshold)

Expected SWOT hydrologic data products

- Every 21 days, SWOT will provide a global assessment of fresh water elevations with accuracy <10 cm and extent for
  - Lakes whose area is > than 1 km^2 (25 cm for lakes > $(250\ m)^2$)
  - Rivers whose width is > 100 m
- These data are sufficient to monitor storage change (but not absolute storage) during the mission lifetime
- Estimates of river discharge using Manning's equation
  - Alternately, using assimilation into hydrodynamic models
- SWOT data products, the details of which are still evolving, are targeted primarily for science users while engaging early adopters:
  - Science data: very high resolution elevations and inundation maps
  - Application data: every 21 days, global lake/wetland inundation polygons with mean elevations
  - Science/applications: river discharge (non real time)
  - Studying options to enable Near Real-Time products

Discharge Product

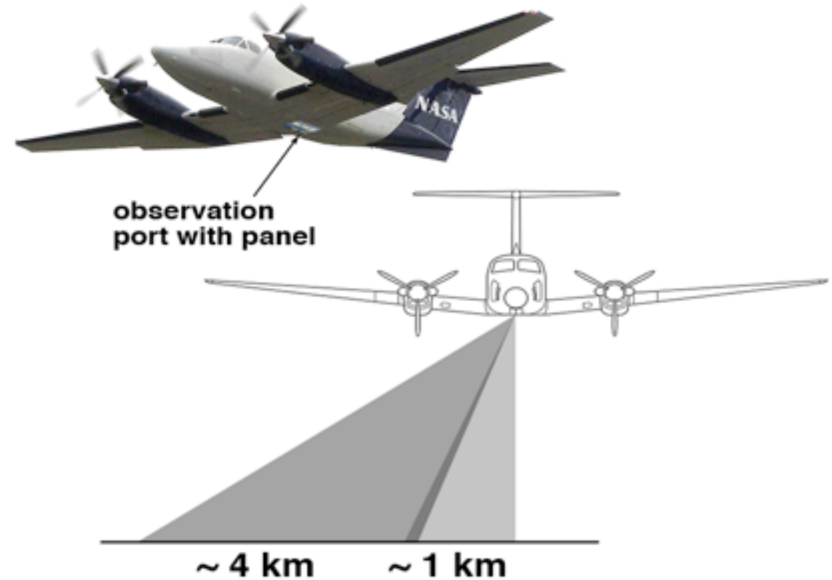
- Discharge is not directly measured by either stream-gauges or from satellite measurements
  - For both cases, discharge is ***estimated*** from other measurements (e.g., rating curves for gauges)
  - SWOT will provide estimates of discharge based on multiple SWOT measurements (stage, slope, width), and the observation of river dynamics over the SWOT lifetime (with complimentary, but not required, in situ data).
- Discharge performance will be ***characterized.***
- Two open community meetings of hydrologists have approved the following plan:
  - There are many regions of the world where no discharge measurements are openly available or available at all, ***making the global assessment of river discharge currently impossible***.
  - Given the peculiarities of river morphology and dynamics and discharge basin area, it is not possible to arrive at a ***global discharge requirement.***
  - ***Global*** estimates of discharge are a unique SWOT product and will be revolutionary for the community, as long as the discharge error is characterized
  - Error characterization plans are acceptable: USGS and stream gauges in France are available for comparison to SWOT discharge. AirSWOT campaigns will be valuable for understanding discharge algorithm performance across scales.

AirSWOT on NASA King Air B200

A Ka-band SWOT Phenomenology Airborne Radar (KaSPAR)

Calibration/Validation Sensor

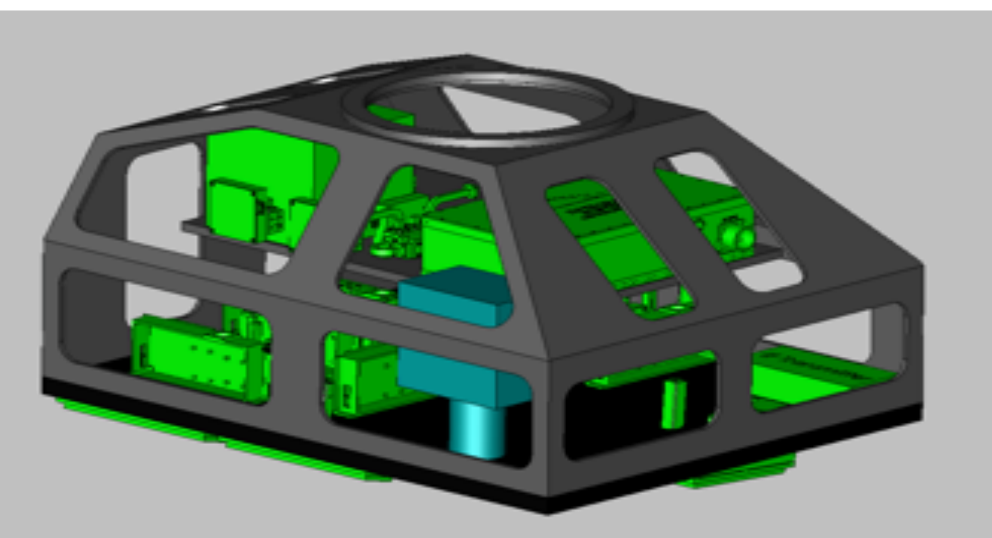
•The high-precision swath elevation mapping capability will enable calibration and validation of the SWOT ocean-surface and hydrologic feature heights in a way not previously practical



Primary measurement product:

•High accuracy elevation maps with ~5km swath (at 35kft) over ocean and terrestrial water bodies

-Traditional altimeter height retrieval to provide tie points for swath edges

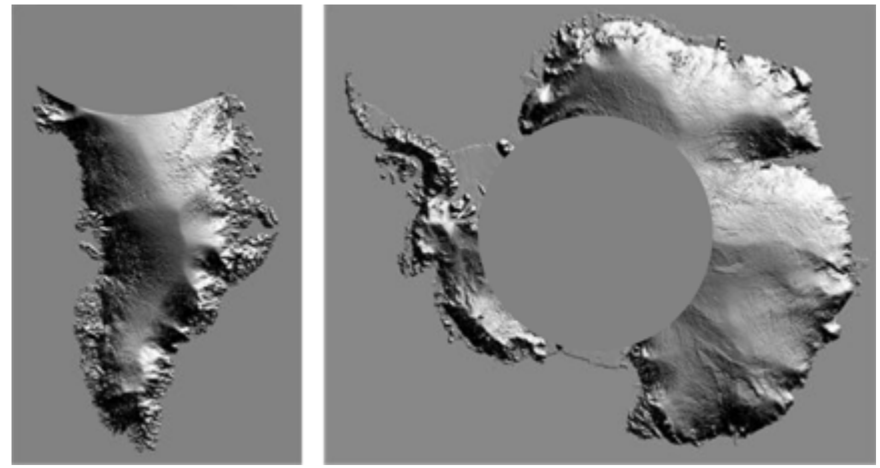


Synergistic Objectives (not driving mission design)

Sea Ice Freeboard

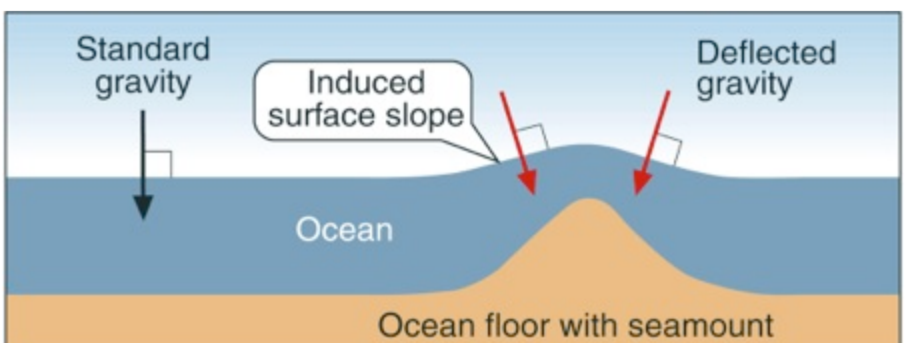
Sea ice thickness reflects the energy balance of the growth and decay of sea ice with great importance to climate change and societal applications.

Ice Sheet Topography



The melt of ice sheet is a major source of sea level rise from climate change.

Ocean Bathymetry



The high precision of SWOT measurement of sea surface height coupled with the full spatial coverage will make significant advance in the knowledge of ocean bathymetry with advances in both science and applications. (from 3 μrad to < 1 μrad)

Complementary measurements & missions

- SMAP & GPM: coincident operation presents a unique opportunity for global water budget studies
- GPS/Doris observations complement CLARREO
- CryoSat, airborne Ka-band measurements: river phenomenology
- OSTM/Jason-2, Jason-3, IceSat2: some lake & river data is collected by these satellites
- ALOS/PalSAR: water body mask useful for planning & climatology
- Jason-series altimeters, : complementary ocean data
- SAR missions : Sentinel-series (1, 3), others
- IceSat
- High resolution SST, ocean color, vector winds
- CFOSAT – French-Chinese wind-wave mission

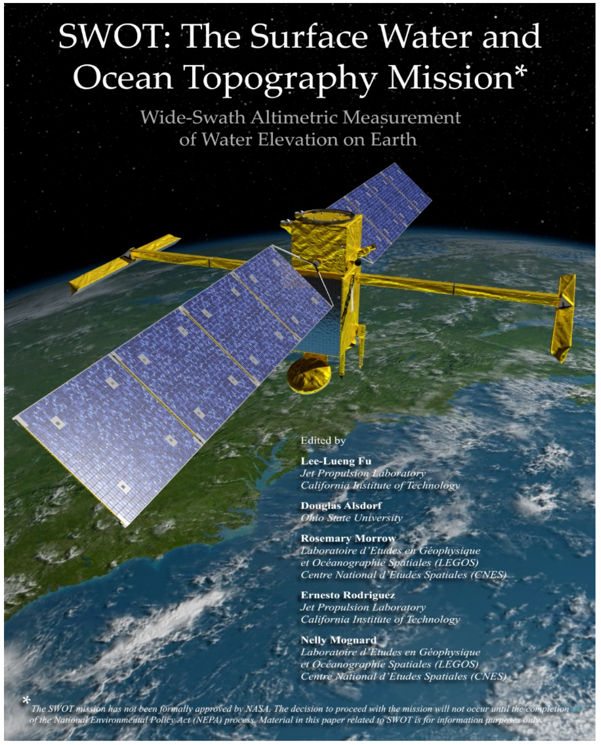
Summary

- The Surface Water Ocean Topography (SWOT) Mission provides for a **quantum improvement for oceanography and hydrology from the next generation altimeter mission.**

  - Oceanography: *First global determination of the ocean circulation, kinetic energy and dissipation at high resolution.*

  - Hydrology: *First global inventory of fresh water storage changes, river discharge and flux on a global basis*

- One of two Earth Science Decadal Survey Tier 2 satellite missions identified **for launch by 2020**



Summary

- Mission is planned as **a major partnership with the French Space Agency (CNES)** continuing a ~20 year collaboration on highly successful oceanographic satellite missions.
- New partnerships with **Canadian Space Agency (CSA)** & **United Kingdom Space Agency (UKSA)**
- The global water science communities are invited to participate via the competed NASA & CNES SWOT science team and the SWOT applications team
  - For more info see :

    http://swot.jpl.nasa.gov

    http://www.aviso.altimetry.fr/swot